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4. TITLE AND SUBTITLE	
Fundamental investigations into the infrared properties of carbon nanotubes Final Report (ARO W911NF-09-1-0295) August 1, 2009- October 31, 2012	5a. CONTRACT NUMBER W911NF-09-1-0295
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 611102
6. AUTHORS Dr. Judy Wu	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES	8. PERFORMING ORGANIZATION REPORT NUMBER
University of Kansas Center for Research, Inc. University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66045 -7568	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSOR/MONITOR'S ACRONYM(S) ARO 11. SPONSOR/MONITOR'S REPORT NUMBER(S) 56050-EL.21

12. DISTRIBUTION AVAILIBILITY STATEMENT

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13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

Carbon nanotubes (CNTs) have outstanding photoresponse in the IR range. Their unique one-dimensional electronic configuration, special band structure and novel electron/phonon transport properties project a promisingly high detectivity D* for IR detection. Our recent work on individual multiwall CNT nanobolometers has made exciting progress towards this with high D* up to 3.2x109 cm?Hz1/2/W achieved at room temperature. In addition, the nanofabrication approach developed in our laboratory on suspended CNT thin film IR detectors allows

15. SUBJECT TERMS

infrared detectors, carbon nanotubes, schottky junctions, bolometers

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Judy Wu
UU	UU	UU	UU		19b. TELEPHONE NUMBER 785-864-3240

Report Title

Fundamental investigations into the infrared properties of carbon nanotubes
Final Report (ARO W911NF-09-1-0295)
August 1, 2009- October 31, 2012

ABSTRACT

Carbon nanotubes (CNTs) have outstanding photoresponse in the IR range. Their unique one-dimensional electronic configuration, special band structure and novel electron/phonon transport properties project a promisingly high detectivity D* for IR detection. Our recent work on individual multiwall CNT nanobolometers has made exciting progress towards this with high D* up to 3.2x109 cm?Hz1/2/W achieved at room temperature. In addition, the nanofabrication approach developed in our laboratory on suspended CNT thin film IR detectors allows a controllable thermal link and hence optimized detector performance in CNT thin film IR detector arrays. The proposed research intends to address several critical issues in further development of the individual and thin film CNT IR detectors. On the former, our focus will be on investigating charge/phonon transport and opto-electro properties at microscopic scales. On the latter, we intend to understand so as to engineer the inter-tube electron/phonon transport to approach or exceed the intra-tube limit. Nanofabrication schemes for scale-up the CNT IR detectors for IR imaging will also be explored. The overall goal of this project is to achieve a thorough understanding of the basic physics so as to achieve uncooled CNT IR detectors with high sensitivity, light weight, and low cost.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
01/17/2013	4.00	Jack J. Shi, Judy Z. Wu. Micromechanical Model for Self-Organized Secondary PhaseOxide Nanorod Arrays in Epitaxial YBa2Cu3O7?□ Films, Philosophical Magazine, (12 2012): 0. doi: 10.1080/14786435.2012.705035
01/17/2013	19.00	Rongtao Lu, Caleb Christianson, Alec Kirkeminde , Shenqiang Ren, Judy Wu. Extraordinary Photocurrent Harvesting at Type-II HeterojunctionInterfaces: Toward High Detectivity Carbon Nanotube InfraredDetectors, Nano Letters, (11 2012): 6244. doi:
01/17/2013	17.00	Brian Ruzicka, Shuai Wang, Jianwei Liu, Kian-Ping Loh, Judy Wu, Hui Zhao. Spatially resolved pump-probe study ofsingle-layer graphene produced bychemical vapor deposition [, Optical Materials Express, (06 2012): 700. doi:
01/17/2013	11.00	Zhuangzhi Li, Caitlin Rochford, F. Javier Baca, Jianwei Liu, Jun Li, Judy Wu. Investigation into Photoconductivity in Single CNF/TiO2-Dye Core–Shell Nanowire Devices, Nanoscale Research Letters, (06 2010): 0. doi: 10.1007/s11671-010-9665-3
01/17/2013	10.00	Jianwei Liu, Judy Wu, Christina M. Edwards, Cindy L. Berrie, David Moore, Zhijun Chen, Victor A. Maroni, M. Parans Paranthaman, Amit Goyal. Triangular Graphene Grain Growth on Cube-Textured Cu Substrates, Advanced Functional Materials, (10 2011): 0. doi: 10.1002/adfm.201101305
01/17/2013	8.00	Guowei Xu, Jianwei Liu, Qian Wang, Rongqing Hui, Zhijun Chen, Victor A. Maroni, Judy Wu. Plasmonic Graphene Transparent Conductors, Advanced Materials, (03 2012): 0. doi: 10.1002/adma.201104846
01/17/2013	7.00	Fengli Wang, Navaneetha K. Subbaiyan, Qian Wang, Caitlin Rochford, Guowei Xu, Rongtao Lu, Alan Elliot, Francis D'Souza, Rongqing Hui, Judy Wu. Development of Nanopatterned Fluorine-Doped Tin Oxide Electrodes for Dye-Sensitized Solar Cells with Improved Light Trapping, ACS Applied Materials & Interfaces, (03 2012): 0. doi: 10.1021/am201760q
01/17/2013	6.00	Jack J. Shi, Judy Z. Wu. Structural transition of secondaryphase oxide nanorods in epitaxialYBa2Cu3O7-? films on vicinal substrates, Philosophical Magazine, (12 2012): 0. doi: 10.1080/14786435.2012.682173
01/17/2013	5.00	Alec Kirkeminde, Markus Retsch, Qian Wang, Guowei Xu, Rongqing Hui, Judy Wu, Shenqiang Ren. Surface-passivated plasmonic nano-pyramids for bulk heterojunction solar cell photocurrent enhancement, Nanoscale, (06 2012): 0. doi: 10.1039/c2nr30735a
08/30/2011	1.00	Rongtao Lu, Rayyan Kamal, Judy Z Wu. A comparative study of 1/, Nanotechnology, (07 2011): 0. doi: 10.1088/0957-4484/22/26/265503
08/30/2011	2.00	Caitlin Rochford, Rongtao Lu, Guowei Xu, Judy Wu, Christina M. Edwards, Cindy L. Berrie, Zhijun Chen, Victor A. Maroni, Jianwei Liu. Doped graphene nanohole arrays for flexible transparent conductors, Applied Physics Letters, (04 2011): 0. doi: 10.1063/1.3610939

TOTAL: **11**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
01/17/2013	12.00	Caitlin Rochford, Zhuangzhi Li, Javier Baca, Jianwei Liu, Jun Li, Judy Wu. The effect of annealing on the photoconductivity of carbon nanofiber/TiO2core-shell nanowires for use in dye-sensitized solar cells, Appl. Phys. Lett., (07 2010): 43102. doi:
01/17/2013	13.00	Rongtao Lu, Zhuangzhi Li, Guowei Xu, Judy Wu. Suspending single-wall carbon nanotube thin film infrared bolometerson microchannels, Appl. Phys. Lett., (04 2009): 163110. doi:
01/17/2013	14.00	Rongtao Lu, Jack Shi, Javier Baca, Judy Wu. High performance multiwall carbon nanotube bolometers, Journal of Applied Physics, (10 2010): 84305. doi:
01/17/2013	15.00	Alan Elliot, Ronald Vallejo , Rongtao Lu, Judy Wu. Development of Textured Magnesium Oxide Templates on Amorphous Polymer SurfacesUsing Ion-Beam-Assisted Deposition, Applied Physics Express, (06 2011): 65502. doi:
01/17/2013	16.00	Brian Ruzicka, Lalani Werake, Guowei Xu, Jacob Khurgin, E. Ya. Sherman, Judy Wu, Hui Zhao. Second-Harmonic Generation Induced by Electric Currents in GaAs, Physical Review Letters, (02 2012): 77403. doi:
01/17/2013	18.00	Bing Li, Jianwei Liu, Guowei Xu, Rongtao Lu, Lianghuan Feng, Judy Wu. Development of pulsed laser deposition for CdS/CdTe thin film solar cells, Appl. Phys. Lett., (10 2012): 153903. doi:
01/17/2013	20.00	Pengchen Hu, Bing Li, Lianghuan Feng, Judy Wu, Haibo Jiang, Huimin Yang, Xinju Xiao. Effects of the substrate temperature on the properties of CdTe thin films deposited bypulsed laser deposition?, Surface & Coatings Technology, (10 2012): 84. doi:

TOTAL: **7**

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

08/30/2011 3.00 Jianwei Liu, Judy Wu, Christina M. Edwards, Cindy L. Berrie, David Moore, Zhijun Chen, Victor A. Maroni, M. Parans Paranthaman, Amit Goyal. Triangular Graphene Grain Growth onCube-Textured Cu Substrates,
Advanced Functional Materials (08 2011)

TOTAL: 1

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

1) Multiwall Carbon Nanotube bolometers
2) Floating growth of semiconductor nanostructures on graphene
3) Plasmonic and photonic graphene transparent conductors

Patents Awarded

Awards

Logan Wille received 2012 Goldwater scholarship,
Caleb Christianson is the recipient of 2012 Special Student Leadership award, NSF STEM scholarship on Nanotechnology for Renewable Energy in both 2011 and 2012.
Logan Wille received KU undergraduate research awards during the project period
Caleb Christianson received KU undergraduate research awards during the project period
Ben Weitrub received KU undergraduate research awards during the project period

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Rongtao Lu	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Logan Wille	0.50	Physics/ Engineering physics
Caleb Christianson	1.00	Physics/ Engineering physics
Ben Weitrub	0.50	Physics/ Engineering physics
FTE Equivalent:	**2.00**	
Total Number:	**3**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period:	0.00
The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:......	0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):......	0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:......	0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense	0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:......	0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

5 **MWCNT Opto-Electronic Devices**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) N

Foreign Countries of application (5g-2):

5a: Rongtao Lu

5f-1a:

5f-c:

5a: Judy Wu

5f-1a:

5f-c:

5 **Plasmonic Graphene and Method of Making the Same**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) N

Foreign Countries of application (5g-2):

5a: Jianwei Liu

5f-1a:

5f-c:

5a: Judy Wu

5f-1a:

5f-c:

5a: Guowei Xu

5f-1a:

5f-c:

5 **Semiconductor-Graphene Hybrids Formed Using Solution Growth**

Patent Filed in US? (5d-1) Y

Patent Filed in Foreign Countries? (5d-2) N

Was the assignment forwarded to the contracting officer? (5e) N

Foreign Countries of application (5g-2):

5a: Jianwei Liu

5f-1a:

5f-c:

5a: Judy Wu

5f-1a:

5f-c:

Scientific Progress

Fundamental investigations into the infrared properties of carbon nanotubes
Final Report (ARO W911NF-09-1-0295)
August 1, 2009- October 31, 2012
PI Name: Judy Wu
PI Address: Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045
PI phone: (785) 864-3240, PI fax: (785) 864-5262; PI email: jwu@ku.edu

This is the final report of the ARO W911NF-09-1-0295 grant, which is three-year mainly supporting one postdoc-Dr. Rongtao Lu on experimental studies of carbon nanotube (CNT) infrared (IR) detectors at the University of Kansas (KU). The original period covered by the grant is August 1, 2009- July 31, 2012. A three-month no cost extension was requested/approved to cover the gap between this grant and the renewal grant of this project. The central focus of the proposed research is to achieve a thorough understanding of the basic physics that governs the IR response in individual and thin film CNTs. The ultimate goal is to develop uncooled CNT IR detector arrays on Si with high sensitivity, light weight, and low cost that meets the US Army's updated requirements for anti-terrorist attacks and homeland security.
The focus of the project is to achieve a thorough understanding of the basic physics that governs the IR response in individual and thin film CNTs in order to enhance the performance of CNT IR detectors. The major achievements include: 1) designed an unique configuration of individual MWCNT IR detector with asymmetric Schottky electrodes to facilitate photocurrent generation/collection from all inner CNT shells and demonstrated outstanding D* in exceeding 109 cm¿Hz1/2/W, three orders of magnitude higher than previously reported on CNT based IR detectors; 2) developed novel MWCNT film IR detector and obtained the best so far D*~3x106 cm¿Hz1/2/W on CNT films and also systematically explored the noise property and provided more information on optimizing the device performances; 3) developed scalable microfab procedure for suspending SWCNT film IR bolometer with improved D* by an order of magnitude as compared with the unsuspended one; 4) tested the idea of using graphene flakes to modify the inter-tube junction in CNT film and achieved a factor of 5-10 improvement in D*; 5) explored P3HT passivated s-SWCNT (not in the original proposal) for effective exciton dissociation and demonstrated higher D* in exceeding D*~108 cm¿Hz1/2/W; and 6) explored (not in the original proposal) graphene-based photodetectors by using plasmonic/photonic, and nanowire hybrid nanostructures. The details will be discussed in the final report of this project and 23 manuscripts (19 published/accepted, 2 submitted and 2 preprints). In addition, 3 patent applications have been submitted. This project also provides unique education at various levels. The PI participated in the 2010 and 2011 ARO HSAP program and recruited 4 outstanding local high school students for summer research, all are pursuing careers in STEM disciplines. The project has also supported three outstanding undergraduate researchers, Logan Wille, Caleb Christianson and Ben Weitrub, all are in physics/engineering physics. Logan Wille received 2012 Goldwater scholarship, Caleb Christianson is the recipient of 2012 Special Student Leadership award, NSF STEM scholarship on Nanotechnology for Renewable Energy in both 2011 and 2012. All three received KU undergraduate research awards during the project period.
Topic 1- CNT, CNT/graphene and graphene thin film IR bolometers
To further explore the mechanism of IR response and confirm the bolometric response in CNT films, a systematic study of IR response at different incident IR spot positions was started and interesting preliminary results have been obtained. The IR laser with 1.5 μm wavelength was generated by an IR diode and carried to the CNT film through an open end optical fiber. Since the optical fiber core diameter is only about 10 μm, which is much smaller than the CNT film dimension of normally about 0.2-0.3 mm between two adjacent voltage leads, as long as the probe is brought close enough to the CNT film surface the incident IR spot is localized to a certain region and then the position effect can be measured. The preliminary scan results at the same bias currents but two different IR power levels show the maximized response is observed at the position close to the center of CNT film between voltage electrodes. This phenomenon is different from some previous reports that photoresponse in CNT film is maximized at film-electrode interface and switches polarity when IR spot is moved from one electrode to the other, which indicates the generation of photocurrent. This result observed in our experiment is consistent with the bolometric mechanism since at the center position of CNT film IR induced heat is maximized and the thermal dissipation to environment is minimized; when IR spot is moved towards to electrode the thermal conduction to environment increases due to the closer distance to electrode and once the spot is moved onto electrode the response is minimized.
Since bolometric response has been confirmed in our experiments and photocurrent response was reported by other groups in CNT films, it means the dominant mechanism varies at different conditions. We suspect the film-electrode contact may make big difference since a large Schottky potential, if exists, will contribute a lot to photocurrent generation. In CNT films, the pristine CNT film-electrode contact may not be good Ohmic contact and thermal annealing will greatly improve it. We are designing experiments and will investigate the annealing effect using this kind of IR scanning method.
One of the more recent efforts in this project was to explore photonic, instead of bolometric photoresponse in CNT or carbon nanostructured IR photodetectors. A novel scheme of type-II heterojunctions formed at the interface between purified semiconducting single-wall CNT and conjugated semiconducting polymer of P3HT was one such example. Extraordinary photoresponse has been obtained in the s-SWCNT/P3HT nanohybrid IR detectors, which not only yield the best so far achieved D* in exceeding 3.0¿108 cm.Hz1/2/W in NIR spectrum, but also fast photoresponse time of <1 millisecond, which does not seem to depend on the thermal link of the detector unit with the environment. The external quantum efficiency up to 86% has been demonstrated. This result is first demonstration of photonic IR detector based on CNT (all previous ones are based on bolometric effect) and opens the way for high-performance photonic CNT IR detectors at low cost. In addition, the method is scalable to large arrays of the IR detectors.

Another new direction we have explored is graphene or graphene/CNT composites for photo detection. Graphene has been very attractive for electronics applications due to its high mobility and conductivity (but no band gap). Also graphene and CNT have good compatibility since they are both carbon based materials. Mixing graphene in CNT films may greatly modify the electrical properties of a CNT film due to the good conductivity and large surface area of graphene. In a recent work by mixing 30% graphene flakes (by weight) to MWCNT films, about an order of magnitude enhancement of photoresponsivity and detectivity D* have been achieved (a manuscript has been developed and will be submitted soon). It has been discovered that the role of the graphene flakes is in raising the IR photoresponse of the graphene/CNT composites via formation of the Schottky junctions that provide local exciton dissociation mechanism, which is another photonic mechanism for IR detection. This observation is highly interesting and important to development of high-performance, low-cost carbon nanostructured IR detectors and detector arrays using self-assembly methods. In addition, we have made photonic and plasmonic graphene. Investigation of their photoresponse is ongoing.

Topic 2-Enhancing Detectivity D* of Individual CNT IR photo detector

CNTs, in either single-wall (SWCNT) or multiwall (MWCNT) form, show outstanding absorption and photoresponse in infrared (IR) spectrum, making them promising candidates for IR detector applications. Many attempts have been made in fabrication and characterization of IR detectors by employing film and individual CNTs as the detection elements. Although promising results have been obtained, the figure-of-merit detectivity D* of the CNT IR detectors is several orders of magnitude lower than that of their conventional counterparts. On SWCNT and MWCNT film IR detectors, the best D* is 4.5¿105 and 3.3¿106 cm¿Hz1/2/W, respectively. These D* are at least two orders of magnitude lower than that of 108 cm¿Hz1/2/W in the uncooled vanadium oxide (VOx) IR bolometers. Individual CNT IR detectors are promising to achieving higher D* by removing the intertube junctions-obstacles for charge transport in CNT films, but little has been reported so far primarily because of the low IR responsivity on individual CNTs. Further improving the performance of CNT IR detectors is necessary and imperative in order to make them competitive for practical applications.

We have explored several different schemes of individual MWCNT IR detectors. One is bolometer with two Ohmic contacts (Pd) on a MWCNT sidewall). Another is photo detector with asymmetric Schottky contacts (Ti/Au) on a MWCNT. One of the Schottky contact is on the sidewall and the other covering the end of the MWCNT so connection to all inner CNT shells is established. No detectable photoresponse on the individual MWCNT bolometer was obtained. In contrast, high detectivity D* up to 6.2¿109 cm.Hz1/2/W has been obtained on individual MWCNT IR photodetectors with asymmetric Schottky contacts. While more systematic studies are underway to pinpoint the mechanism responsible for the much enhanced RI obtained on the individual MWCNT with asymmetric Schottky contacts, we argue that several unique features combined together in this kind of devices may contribute directly to the improved performance. First, the asymmetric Schottky contacts with one connected to all inner CNT shells may provide favorable pathways for collecting photocurrent from the inner shells. Considering all inner CNT shell absorb light in a similar way, the increase of the photocurrent could be proportional to the number of inner CNT shells up to an optimal MWCNT diameter (or number of inner shells) based on light absorption, which is on the order of 50-100 nm. On the other hand, the Schottky contacts have much reduced thermal link as compared to the Ohmic ones typically used for the Schottky devices. This may result in considerably enhanced detector element temperature exceeding the exciton binding energy and consequently lead to thermally assisted generation of photocurrent.

Moreover, we are working on transferring the photoresponse scan measurement used on CNT films to individual CNTs and measure the two dimensional response maps. The near-field scanning microscope technique can be applied onto individual CNTs as long as very sharp fiber tip can be obtained. We have successfully pulled optical fiber with cladding diameter around 100 μm into sharp tip with tip diameter of ¿ 0.1 μm. We're now working on coating metal onto the sidewall and make very small aperture on the tip end for the near field scanning measurements.

Patents:

1. (pending) Judy Wu and Rongtao Lu, “Multiwall Carbon Nanotube bolometers”, utility patent application filed on Oct. 11, 2011.
2. (pending) Jianwei Liu, Judy Wu, “Floating growth of semiconductor nanostructures on graphene”, utility patent application submitted in Oct. 2012.
3. (pending) Judy Wu, Guowei Xu and Jianwei Liu, “Plasmonic and photonic graphene transparent conductors”, utility patent application filed in Oct. 2012.

Publications (2 preprints, 2 submitted, and 19 published/accepted)

1. G. Xu, H.-Y. Chiu, J. Liu, C. Rochford and J. Wu,"Plasmonic graphene based photodetector", preprint .
2. C. Christianson, R. T. Lu, B. Weintrub and J. Wu,"A comparative study of MWCNT film bolometers with different diameters", preprint.
3. Rongtao Lu, Caleb Christianson, and Judy Wu, “Improved infrared photoresponse in CNT/graphene composite films”, submitted in Nov., 2012
4. Jianwei Liu, Rongtao Lu, Guowei Xu, Judy Wu, Prem Thapa, David Moore, “Development of a solution-based floating growth process for synthesis of ZnO micro/nanowire arrays on graphene: towards high-performance nanohybrid ultraviolet photodetectors”, submitted in Nov., 2012
5. Steven Klankowski, Ronald Rojeski, Brett Cruden, Jianwei Liu, Judy Wu, Jun Li, “High-Performance Lithium-ion Battery Anode Based on Core-Shell Heterostructure of Silicon-Coated Vertically Aligned Carbon Nanofibers”, to appear in Journal of Mat. Chem. A 2013
6. Pengchen Hu, Bing Li, Lianghuan Feng, Judy Wu, Haibo Jiang, Huimin Yang, Xinju Xiao, “Effects of the substrate

temperature on the properties of CdTe thin films deposited by pulsed laser deposition", Surface & Coatings Technology 213, 84 (2012); doi.org/10.1016/j.surfcoat.2012.10.022
7. Rongtao Lu, Caleb Christianson, Shenqiang Ren, and Judy Wu, "Extraordinary Photocurrent Harvesting at Type-II Heterojunction Interfaces: Towards High Detectivity Carbon Nanotube Infrared Detectors", Nano Letters 12, ?? 2012. DOI:10.1021/nl03302p
8. Bing Li, Jianwei Liu, Guowei Xu, Lianghuan Feng and Judy Wu, "Development of Pulsed Laser Deposition for CdS/CdTe Thin Films Solar Cells", Applied Physics Letters 101, 153903 (2012).
9. Jack Shi and Judy Wu, "Transition of Orientation of Impurity Nanorod Arrays in Epitaxial YBCO Film on Vicinal Substrates", Philosophic Magazine (2012). DOI: 10.1080/14786435.2012.705035
10. Alec Kirkeminde, Markus Retsch, Qian Wang, Furui Tan, Guowei Xu, Rongqing Hui, Judy Wu, Shenqiang Ren, "Surface-Passivated Plasmonic Nano-Pyramids for Bulk Heterojunction Solar Cell Photocurrent Enhancement", Nanoscale 4, 4421 (2012), also featured on the cover of the issue 14. DOI: 10.1039/C2NR30735A
11. J. Shi and J.Z. Wu, "Micromechanical model for self-organized secondary phase oxide nanorod arrays in epitaxial YBa2Cu3O7-d films", Philosophic Magazine (2012) DOI:10.1080/14786435.2012.682173
12. B. Ruzicka, Shuai Wang. Jianwei Liu, Kian-Ping Loh, J.Z. Wu, Hui Zhao, "Spatially resolved pump-probe study of graphene produced by chemical vapor deposition [invited], Optical Materials Express Vol. 2, Iss. 6, pp. 700–707 (2012).
13. Fengli Wang, Navaneetha K. Subbaiyan, Qian Wang, Francis D'Souza, Ron Hui, and Judy Wu, "Development of Nanopatterned photonic Fluorine-doped Tin Oxide Electrode for High-efficiency Dye Sensitized Solar Cells with Improved Light Trapping", ACS Applied Materials and Interfaces 4, 1565-1572 (2012). DOI: 10.1021/am201760q
14. Guowei Xu, Jianwei Liu, Qian Wang, Ronqing Hui, Zhijun Chen, Victor A. Maroni, Judy Z. Wu, "Development of Plasmonic Graphene Transparent Electrode", Advanced Materials 24, OP 71-76, cover article of March issue of the Advanced Optical Materials-a quarterly forum of the very best articles on light-matter interaction. DOI: 10.1002/adma.201104846
15. Brian A. Ruzicka, Lalani K. Werake, Guowei Xu, Jacob B. Khurgin, E. Ya. Sherman, Judy Z. Wu, and Hui Zhao, "Second-harmonic generation induced by electric currents in GaAs", Physical Review Letters 108, 077403 (2012). Highlighted in Physics Today 65(3), 15 (2012); doi: 10.1063/PT.3.1461
16. Jianwei Liu, Judy Wu, Tina Edwards, Cindy Berrie, David Moore, Javier Baca, Zhijun Chen, Victor A. Maroni, M. Parans Paranthaman, Amit Goyal, "Triangle graphene grain growth on cubic-textured cu substrates", Advanced Functional Materials, 21, 3868 (2011), DOI: 10.1002/adfm.201101305
17. Jianwei Liu, Guowei Xu, Caitlin Rochford, Rongtao Lu, Zhijun Chen, Victor A. Maroni, Tina Edwards, Cindy Berrie, and Judy Wu, "Graphene photonic crystal for broadband flexible transparent conductors", Applied Physics Letters 99, 023111 (2011)
18. A. Elliot, Vallejo, R.T. Lu, and J.Z. Wu, "Development of Textured Magnesium Oxides Templates on Amorphous Polyimide Films by Ion Beam Assisted Deposition", Applied Physics Express Letters 4, 065502 (2011).
19. R.T. Lu, R. Kamal, and J.Z. Wu, "A Comparative Study of 1/f Noise and Temperature Coefficient of Resistance in Multiwall and Single-Wall Carbon Nanotube Bolometers", Nanotechnology 21, 265503 (2011).
20. Rongtao Lu, Jack J. Shi, F. Javier Baca, and Judy Z. Wu, "High Performance Multiwall Carbon Nanotube Bolometers", J. Appl. Phys. 108, 084305 (2010).
21. R.T. Lu and J.Z. Wu, "Suspending Single-Wall Carbon Nanotube Film Infrared Bolometers on Nanopillars", Appl. Phys. Lett. 94, 163110 (2009).
22. C. Rochford, Z.Z. Li, J. Baca, J.W. Liu, J. Li and J. Wu, "The effect of crystallinity on the photoconductivity of CNF-TiO2-dye core-shell nanowires", Applied Physics Letters 97, 043102 (2010).
23. Z.Z. Li, C. Rochford, J. Baca, J.W. Liu, J. Li, and J.Z. Wu, "Investigation of photoconductivity in single CNF/TiO2-dye core-shell nanowire devices", Nanoscale Research Letters (2010) DOI 10.1007/s11671-010-9665-3.

Technology Transfer